Figure 14a: Walton Spring

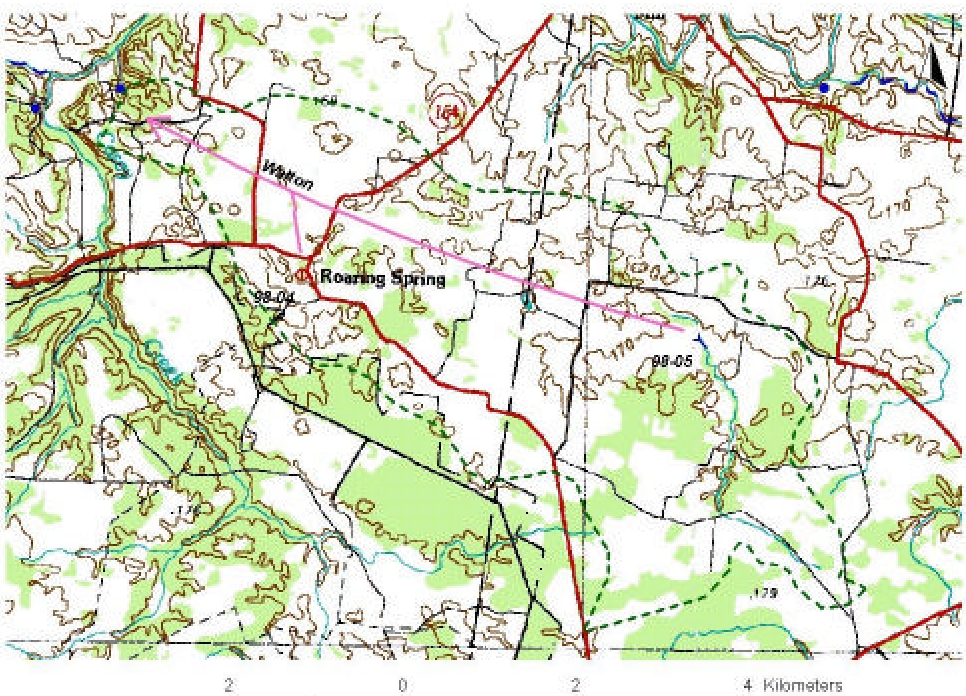

Figure 14b: Walton Spring Basin:
Low-Flow Discharge 48.1 L/s (1.7 ft^3/s); Basin Area 25.1 km^2 (9.7 mi^2); UBF 2.0 $L/s/km^2$ (0.18 $ft^3/s/mi^2$); Land-use 77.4% Agricultural, 7.8% Forest (+11.2 Woody Wetland)

Dye tests of Walton Spring:

98-04

January 29, 1998: 5.7 L (1.5 gal) of optical brightener was injected at **Roaring Spring Sink**. Eight days later Walton Spring (++), 3 km (2 mi) northwest, was very positive, while six other sites were negative. Two karst windows just up-gradient of Walton Spring were also positive.

98-05

January 29, 1998: 340 g (12 oz) of fluorescein was injected at an unnamed creek identified as **Garnett Sinking Creek**. On the second dye receptor exchange, 22 days later, Walton Spring and the karst windows (+++), 7 km (7.5 mi) to the west-northwest, were extremely positive, while seven other sites were negative.

Wright (1475)

Wright Spring (Figures 15a and 15b), in southeast Todd County [N36°-42′-24″; W87°-06′-22″], is a bluehole spring that discharges from the base of a 4 m (12 ft)-high limestone bluff and flows 550 m (1,800 ft), where it sinks at three main swallets over a 120 m (400 ft) channel reach.

Figure 15a: Wright Spring

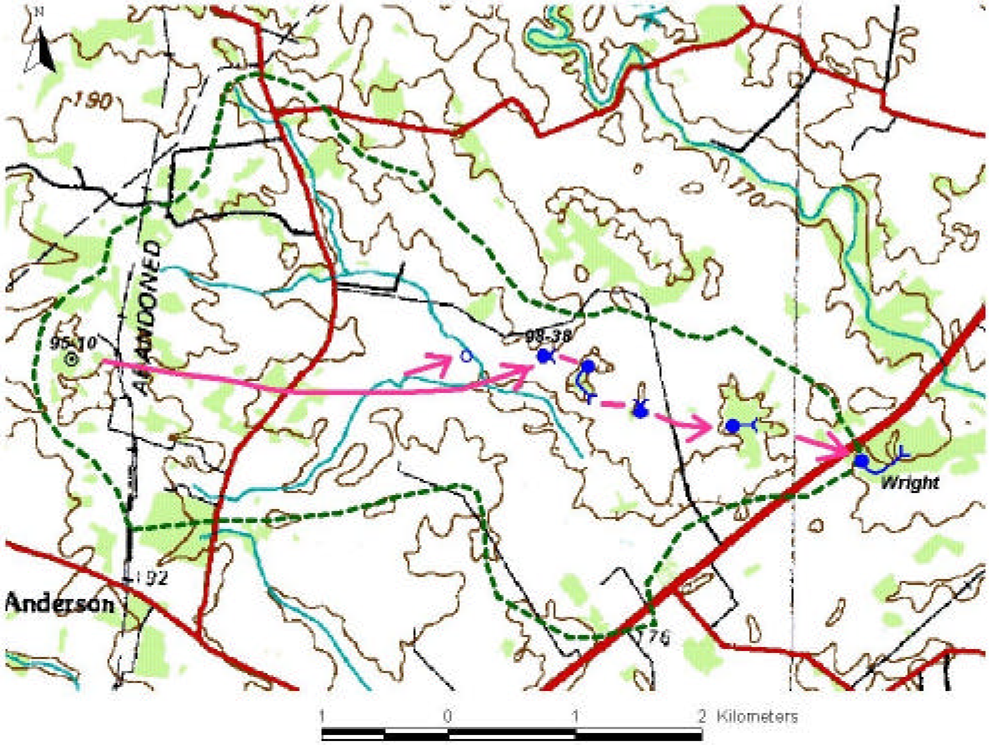

Figure 15b: Wright Spring Basin:
Low-Flow Discharge 25.5 L/s (0.9 ft^3/s); Basin Area 14.2 km^2 (5.5 mi^2);
UBF 1.7 L/s/km^2 (0.16 $ft^3/s/mi^2$); Land-use 89.7% Agricultural, 6.2% Forest

Wright Spring is a long, depression-type karst window, which is mapped on the Allensville 7.5 minute Topographic Quadrangle, but not on the corresponding geologic map. Additionally, four classic collapse-type karst windows (unmapped) are located down-gradient, within 210 m (700 ft) of the primary swallet. Five perennial and one overflow karst windows occur upgradient of Wright Spring. One of the karst windows is pumped as the water supply for a swine operation. Wright Spring discharges from the Ste. Genevieve Limestone (Klemic, 1966) at about 166 m (545 ft) elevation. Low-flow discharge is about 31 L/s (1.1 ft^3/s).

Dye tests of Wright Spring:

Wright Spring, a karst window, was identified in 1995 during Spring Protection Area delineation fieldwork, for Merriwether Spring in Guthrie, Kentucky (Ray and Stapleton, 1996)

95-10

November 30, 1995: 1.4 kg (3 lb) of Direct Yellow 96 was flushed into **Kanagy Sink** with 570 L (150 gal) of water from a local domestic supply. Six days later, Franks Bluehole (+), 4 km (2.5 mi) to the east, was positive. This livestock water supply spring, which is in the mid-portion of the Wright Spring sub-basin, was positive for two additional weeks. A nearby overflow spring feeding Franks Stream was also positive during the trace.

96-02 (Replication)

February 14, 1996: **Wright Spring swallet** was traced with 680 g (1.5 lb) of Direct Yellow 96, beneath the bedrock channel of Elk Fork to Underflow Spring, 1.5 km (1 mi) to the northeast. This test initially failed because only springs on the west side of Elk Fork were monitored.

98-38

July 1, 1998: An additional test was conducted in 1998. 30 g (1 oz) of fluorescein was injected in the downstream portion of **Franks Bluehole** karst window. Eight days later, dye was recovered over a 1.6 km-long (1 mi) flow route through four karst windows upstream of Wright Spring.

Summary of Additional Groundwater Tracer Tests

Northeast Study Area

98-43 Hamilton Hill Bluehole

September 23, 1998: During a tracer study for a Wellhead Protection Area in Ekron, Kentucky, 60 g (2 oz) of fluorescein was injected into **McCoy Sinkhole** and flushed with 1500 L (400 gal) of water. Twelve days later, Hamilton Hill Bluehole (+), 11 km (7 mi) to the north-northwest, was positive. This determination was supported by additional traces from the Ekron area.

98-55

October 1, 1998: 160 g (4.5 oz) of fluorescein was injected into a **modified sinkhole drain at Ekron Trailer Court** with 750 L (200 gal) of flush water. Twenty days later, Hamilton Hill Bluehole (+), 11 km (7 mi) to the north-northwest, was positive.

99-28

See results from French Creek Spring basin.

00-17

June 21, 2000: 400 g (14 oz) of fluorescein was injected with 1500 L (400 gal) of flush water into **Dooley Sinkhole**. Forty-one days later, dye began to emerge from Hamilton Hill Bluehole (+), 11.5 km (7 mi) to the north, and grew stronger over the next few weeks. Nine weeks after injection, dye also began to emerge from French Creek Springs (+), 12 km (7.5 mi) to the north. Dye recovery was delayed and prolonged because of low-flow conditions.

99-27 Burtons Hole

April 30, 1999: 115 g (4 oz) of eosine was injected into **Stull Sinkhole**. Eleven days later, Mystic Spring (+), 14.5 km (9 mi) to the west-southwest, an overflow spring for Burtons Hole, was positive. Twenty days after injection, Burtons Hole (+), 15 km (9.5 mi) to the west-southwest, and Parks Spring run (+), 7.5 km (4.75 mi) to the southwest, were positive. An overflow connection between Burtons Hole basin and Parks Spring overflow features was active during this trace.

May 20, 1999: 450 g (16 oz) of eosine was reinjected with 750 L (200 gal) of flush water into **Stull Sinkhole**. Burtons Hole (+++) was extremely positive 5-6 weeks later, including four additional receptor exchanges. Monitoring was discontinued at Mystic Spring since it was previously established as an overflow spring of the Burtons Hole basin. The overflow connection between Burtons Hole basin and Parks Spring run was not active during the lower-flow conditions of this replication.

99-14 Head of Spring Creek

March 4, 1999: 750 g (26.5 oz) of fluorescein was injected into a sinking spring near **Montgomery Cave**. Twelve days later, the Head of Spring Creek overflow (++), 13.5 km (8.4 mi^2) to the northwest, was very positive, while seven additional sites were negative.

99-15

March 11, 1999: 85 g (3 oz) of eosine was injected into a small tributary sinking into gravel (**Cabin Swallet**), in the headwaters of Sugar Tree Run. Eight days later, the Head of Spring Creek overflow (+), 11.5 km (7 mi) to the north, was positive, while eight sites were negative. This spring was also positive 14 days after injection. Because Burtons Hole lies at the mouth of Sugar Tree Run, an intermittent stream, this trace was hypothesized to flow to Burtons Hole. Instead, this dye flowed north beneath a sandstone-capped topographic divide, into the Head of Spring Creek basin.

99-16 Burtons Hole

March 11, 1999: 140 g (5 oz) of SRB was injected at **Dutchke's Swallet**, a minor karst window. Five days later, Burtons Hole (++), 9.5 km (6 mi) to the west-southwest, and Mystic Overflow (++) were both very positive, while seven other sites were negative. This karst window is in the topographic basin of Dry Valley, a tributary to Sugar Tree Run, and was expected to drain to Burtons Hole.

00-10 Head of Doe Run

May 3, 2000: 225 g (8 oz) of SRB was injected at a small sinking spring called **Red Barn Spring**. Within six days, Head of Doe Run (+), 11 km (7 mi) to the north-northeast, was positive and remained positive until May 23. Ten additional sites were negative for dye. This trace indicated a groundwater velocity in excess of 2 km/day (1.2 mi/day).

00-11 Buffalo Creek Spring

May 4, 2000: 15 g (0.5 oz) of fluorescein was injected into the **swallet of Lost Run**. Five days later, Buffalo Creek Spring (++), 2.5 km (1.5 mi) to the southwest, was very positive. The dye receptor located in Dyer Cave, just south of the swallet, had been removed from the flow and was dry. The flow in Dyer Cave may be related to Lost Run, although the cave discharge appears to be less than the swallet volume.

00-12 Hardin Springs

May 4, 2000: 170 g (6 oz) of eosine was injected into **Lucas Swallet**, about 3 km (1.9 mi) northwest of Custer. This dye was hypothesized to drain northeast to the headwaters of Sinking Creek or southwest to Buffalo Creek Spring. Five days later, six monitoring sites were negative. Seven days later, on May 11, new dye receptors were located at three additional sites. On May 23, 19 days after injection, eosine was recovered from Hardin Springs (+), 15 km (9.5 mi) to the northwest of Lucas Swallet. Watt Hole (++), a deep karst window that is a tributary to nearby Hardin Springs, was also very positive for eosine.

00-13 Head of Drakes Creek

May 4, 2000: 30 g (1 oz) of fluorescein was injected into **Keesee Branch Swallet**. Five days later, Head of Drakes Creek (+++), 2.5 km (1.5 mi) to the southwest, was extremely positive, while five sites were negative. The spring was also positive on May 16.

00-14

May 10, 2000: 60 g (2 oz) of SRB was injected into a stream **Swallet**, in a large sink 12 km (7.5 mi) east-southeast of Dyer, near a mapped elevation point of **630 ft** (192 m). Seven days later, Head of Drakes Creek (++), 4 km (2.5 mi) to the southwest, was very positive, whereas the headwater springs of Sinking Creek were negative. Traces #00-13 and #00-14 help to define the southern limit of the Boiling Springs basin.

00-19 Hardin Springs

August 8, 2000: In order to help define the western boundary of Boiling Springs basin, 225 g (8 oz) of SRB was injected at a **Swallet** in **Sugar Cane Sink**, only 2 km (1.2 mi) west of Sinking Creek. Twenty-two days later, dye was very positive at Hardin Springs (++), 10 km (6.25 mi) to the northwest, but was negative in the Boiling Springs system.

Southwest Study Area

98-20 Garnett Spring

April 8, 1998: 55 g (2 oz) of eosine was injected at **Sholar Swallet**, a losing point on Potts Creek. Seven days later, Garnett Spring (+++), 4 km (2.5 mi) to the east-northeast, was extremely positive whereas Brelsford Spring was negative.

98-21 (non-recovery)

April 8, 1998: 55 g (2 oz) of fluorescein was injected at **Adams Swallet**, a losing point in the headwaters of Burge Creek. This dye was not recovered at Brelsford or Garnett springs after five weeks. The most likely interpretation was that an inadequate amount of dye was used for this injection point.

98-32 Head of Casey Creek

May 15, 1998: 170 g (6 oz) of fluorescein was injected at the **Swallet** of **Skinner Creek**, a losing stream. Four days later, Head of Casey Creek (++), 3.5 km (2 mi) to the northeast, was very positive, while three other sites were negative. Dye emerged from the spring for at least three weeks.

98-22 Adams Spring

April 9, 1998: 85 g (3 oz) of eosine was injected at **Brame Karst Window** that was hypothesized to flow to River Bend Spring. Dye was not recovered after monitoring 14 sites for three weeks. Pete Idstein, of Ewers Water Consultants, later informed DOW that eosine had been detected during this time in Little River at the I-24 bridge.

Additional spring surveying along Little River discovered Adams Spring, which lay 2 km (1.2 mi) upstream of our initial survey starting point. On *June 3, 1998*, 115 g (4 oz) of fluorescein was reinjected at Brame Karst Window. Six days later, Adams Spring (+++), 3 km (2 mi) to the northeast, was extremely positive. Three nearby overflow springs were likewise positive.

99-26 Johnston Spring

April 29, 1999: 55 g (2 oz) of SRB was injected at **Garnett Swallet**, an intermittent sinking stream. Six days later, a string of four karst windows (+) to the southwest and Johnston Spring (+), 5 km (3 mi) to the west-southwest, were positive. On June 3, two additional windows were found along this line and, based on proximity and volume, were assumed to be connected to the flow path. The two windows just west of the dye injection point were also determined to be intermittent.

Information Exchange and Public Education

Initial meetings with County Extension and NRCS agents have been made and preliminary data have been exchanged. A presentation on karst groundwater and pollution prevention was made at the Trigg County Farm Field Day. A presentation of regional information was made at a field and cave trip (7-14-03) within the Boiling Springs groundwater basin to raise awareness of sensitive karst and cave environments. On 11-19-03, a review of karst data generated by this study was presented at the Four Rivers Workshop at Lake Barkley, sponsored by Kentucky Water Watch. Dye-tracing data and numerous information booklets concerning agricultural problems in karst areas have been made available to many farmers and land owners that have graciously granted access to their land and springs for this study. These dye-tracing data comprise a significant portion of the forthcoming Tell City and Hopkinsville, Kentucky, Karst Atlas maps to be published by the Kentucky Geological Survey in cooperation with the Kentucky Division of Water. Consequently, this important regional karst-groundwater information, available in a GIS format, will be provided to federal, state and local authorities on a continuing basis. A poster summarizing the final report will be presented at conferences and distributed to government agencies and the public. The completed report will also available at the Kentucky Division of Water Web site.

RESULTS OF UNIT BASE FLOW ASSESSMENT AND COMPILATION OF BASINS

Selected springs in the study areas were gaged during the fall of one or more of the years, 1997-2001. Drainage basin configurations were estimated, largely from groundwater tracer data and topographic divides. Tracer tests were used to adjust estimated basin outlines to better approximate actual basin boundaries. Data quality was categorized as "poor," "fair" or "good," depending on the level of basin delineation by tracer testing and the apparent quality and number of discharge values. Table 2 (presented in both metric and English versions) indicates that based on the best quality data, a typical volume of base-flow runoff is about 2.19 L/s/km^2 (0.20 ft^3/s/mi^2) for the main karst areas in the SW study area and about 1.64 L/s/km^2 (0.15 ft^3/s/mi^2) in similar settings of the NE study area. Base flow groundwater runoff is about 25% greater in the SW area than the NE. This increased groundwater runoff value in the SW is probably due to 10% higher average rainfall, in addition to greater long-term groundwater storage within thicker soils of the SW study area. Epikarst development and base-flow discharge in both of these regions is assumed to be maximized within the soil-covered outcrop of the Ste. Genevieve and St. Louis limestones. Figure 16 shows the distribution of spring basins in the NE study area.

Among the best-quality data, the 327.6 km^2 (126 mi^2) Boiling Springs basin yields a relatively low UBF of 0.87 L/s/km^2 (0.08 ft^3/s/mi^2), about one-half of the region's typical value of 1.64 L/s/km^2 (0.15 ft^3/s/mi^2). Although neighboring Hardin Springs basin is largely estimated, its low UBF of 0.68 L/s/km^2 (0.06 ft^3/s/mi^2) tentatively supports its estimated basin area. These apparent low anomalies are hypothesized to result from hydrogeologic settings that differ significantly from the typical sinkhole-plain type setting.

About 35%, or 116 km^2 (45 mi^2), of Boiling Spring's basin is capped by Chester siliciclastics, such as the Sample Sandstone. Groundwater runoff from these caprocks is typically reduced to zero during late summer and fall low-flow conditions. Also, much of the exposed Ste. Genevieve Limestone within the southern half of the basin is deeply dissected with fairly rugged relief. The epikarst, which contains most groundwater storage, may be less developed in this type of erosionally dissected limestone surface. Together with thinner soils, the less mature epikarst may yield less groundwater runoff than mature epikarst beneath a flat-lying karst plain.

Assuming groundwater runoff equal to the reference value of 1.64 L/s/km^2 (0.15 ft^3/s/mi^2) for 210 km^2 (81 mi^2) of the limestone outcrop portion of the basin and zero contribution from the sandstone caprock portion, the low-flow basin discharge is calculated at 340 L/s (12 ft^3/s). This volume is only 22% higher than the average gaged low-flow discharge of 278 L/s (9.8 ft^3/s) for Boiling Springs. Accounting for low-storage, immature/shallow soil epikarst in the southern portion of the basin, the average UBF for the limestone area of this basin may be about 1.31 L/s/km^2 (0.12 ft^3/s/mi^2). This estimate suggests that the low anomaly for Boiling Spring's UBF may be due primarily to the hydrogeologic variation of limestone versus sandstone caprock.

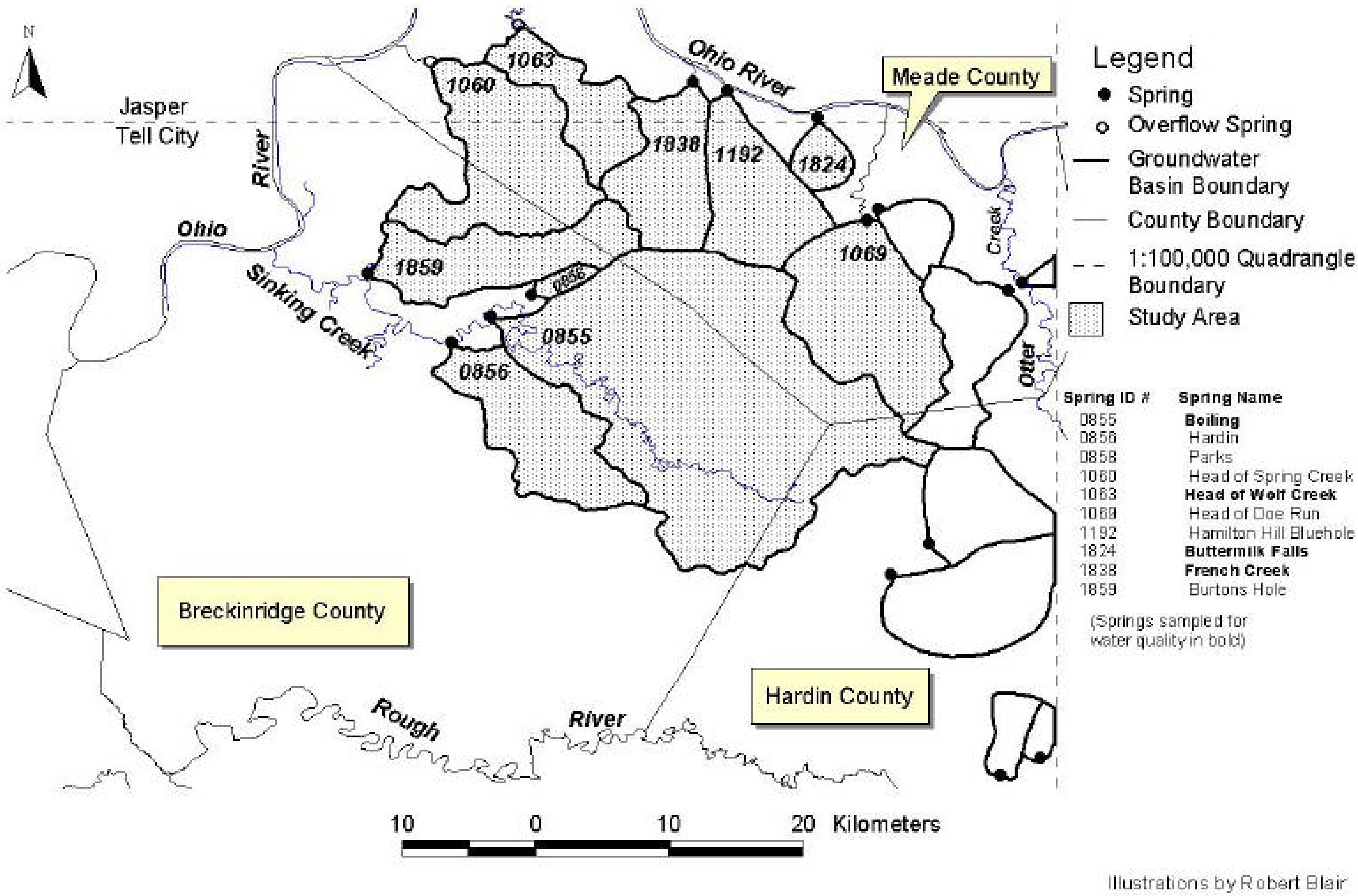

Figure 16: Karst Drainage Basins within the Northeast Study Area

Spring	ID #	Discharge (L/s)	Basin Area (km^2)	UBF ($L/s/km^2$)	Data Quality
Northeast					
Boiling	0855	277.5	327.6	**0.85**	Good
French Creek	1838	45.3	54.4	**0.83**	Fair
Head of Wolf Cr	1063	*14.2 Est*	42.5	*0.33 OF*	Poor
Buttermilk Falls	1824	22.7	12.7	**1.79**	Poor
Head of Doe Run	1070	150.1	94.0	**1.60**	Good
Hamilton Hill BH	1192	93.4	59.3	**1.58**	Fair
Hardin	0856	48.1	71.2	**0.68**	Poor
Head of Spring Cr	1060	28.3	95.8	*0.3 OF*	Poor
Parks	0858	*8.5 Est*	5.2	**1.64**	Poor
Blue	1070	28.3	17.1	**1.66**	Poor
McCraken	2229	87.8	49.0	**1.79**	Good
Burtons Hole	1859	*53.8 Cal*	62.9	*0.85 Ref*	Poor
Southwest					
Mill Stream	0203	82.1	182.1	**0.45**	Fair
Barkers Mill	0859	169.9	69.2	**2.46**	Fair
River Bend	0860	158.6	69.9	**2.27**	Good
Cook	1141	93.4	41.7	**2.24**	Fair
Brelsford	1448	*85.0 Est*	32.9	**2.58**	Poor
King	1489	59.5	28.2	**2.11**	Good
Walton	1457	48.1	25.1	**1.92**	Fair
Wright	1475	25.5	14.2	**1.79**	Fair
Buchanan	0569	42.5	40.1	**1.06**	Fair
Spring Hill/Herndon	1857/1445	53.8	39.9	**1.35**	Fair
Cooksey	0566	101.9	36.3	**2.81**	Good
Hughs BH	1485	62.3	31.3	**1.99**	Good
Meriwether	0038	70.8	30.0	**2.36**	Good
Garnett	1456	76.5	27.2	**2.81**	Fair
Cadiz	0854	59.5	24.1	**2.47**	Fair
Hunt	1487	62.3	54.4	**1.15**	Poor
Henderson	1484	19.8	12.2	**1.63**	Fair
Turner BH	1910	53.8	24.9	**2.16**	Poor
McCraw	1845	11.3	4.9	**2.30**	Poor
Glovers Cave	1486	34.0	15.0	**2.26**	Poor
Hunter	1140	31.1	14.0	**2.23**	Fair
Quarles	2542	45.3	19.4	**2.33**	Good
Head of Casey Cr.	1458	76.5	64.0	**1.20**	Poor
Torian	3117	9.9	12.4	**0.80**	Poor
Murphy	2520	68.0	4.4	**15.44**	Poor
Johnston	1460	*65.1 Cal*	29.8	*2.19 Ref*	Poor
Adams	1905	*31.1 Cal*	14.0	*2.23 Ref*	Poor
Frederick	1867	*11.9 Cal*	5.4	*2.19 Ref*	Poor
Interstate	1858	*65.1 Cal*	29.5	*2.21 Ref*	Poor

Table 2M: Metric Version: Unit Base Flow (UBF) data for NE and SW Portions of the Western Mississippian Plateau.

UBF (shown in bold) is derived by dividing a spring's base-flow discharge by its basin area. Spring volumes that are difficult to gage may be calculated (*Cal*) by multiplying the apparent basin area by the reference (*Ref*) value (basins with calculated discharges, shown in italics, were not used in regression analyses). Three spring volumes were estimated (*Est*). The low UBF of two large overflow (OF) springs results from the diversion of most of the basin's base flow to an unknown location. The metric conversion factor is: **10.931** x ___ $ft^3/s/mi^2$ = ___ $L/s/km^2$. The English conversion factor is: **0.0915** x ___ $L/s/km^2$ = ___ $ft^3/s/mi^2$. *(Some basin areas and UBF have been modified by subsequent research).*

Spring	ID #	Discharge (ft^3/s)	Basin Area (mi^2)	UBF ($ft^3/s/mi^2$)	Data Quality
Northeast					
Boiling	0855	9.8	126.5	**0.08**	Good
French Creek	1838	1.6	21.0	**0.08**	Fair
Head of Wolf Cr	1063	0.5 *Est*	16.4	**0.03** *OF*	Poor
Buttermilk Falls	1824	0.8	4.9	**0.16**	Poor
Head of Doe Run	1069	5.3	36.3	**0.15**	Good
Hamilton Hill BH	1192	3.3	22.9	**0.14**	Fair
Hardin	0856	1.7	27.5	**0.06**	Poor
Head of Spring Cr	1060	1.0	37.0	**0.03** *OF*	Poor
Parks	0858	0.3 *Est*	2.0	**0.15**	Poor
Blue	1070	1.0	6.6	**0.14**	Poor
McCraken	2229	3.1	18.9	**0.16**	Good
Burtons Hole	1859	*1.9 Cal*	*24.3*	*0.08 Ref*	Poor
Southwest					
Mill Stream	0203	2.9	70.3	**0.04**	Fair
Barkers Mill	0859	6.0	26.7	**0.22**	Fair
River Bend	0860	5.6	27.0	**0.21**	Good
Cook	1141	3.3	16.1	**0.20**	Fair
Brelsford	1448	*3.0 Est*	12.7	**0.24**	Poor
King	1489	2.1	10.9	**0.19**	Good
Walton	1457	1.7	9.7	**0.18**	Fair
Wright	1475	0.9	5.5	**0.16**	Fair
Buchanan	0569	1.5	15.5	**0.10**	Fair
Spring Hill/Herndon	1857/1445	1.9	15.4	**0.12**	Fair
Cooksey	0566	3.6	14.0	**0.26**	Good
Hughs BH	1485	2.2	12.1	**0.18**	Good
Meriwether	0048	2.5	11.6	**0.22**	Good
Garnett	1456	2.7	10.5	**0.26**	Fair
Cadiz	0854	2.1	9.3	**0.23**	Fair
Hunt	1487	2.2	21.0	**0.10**	Poor
Henderson	1484	0.7	4.7	**0.15**	Fair
Turner BH	1910	1.9	9.6	**0.20**	Poor
McCraw	1845	0.4	1.9	**0.22**	Poor
Glovers Cave	1486	1.2	5.8	**0.21**	Poor
Hunter	1140	1.1	5.4	**0.20**	Fair
Quarles	2542	1.6	7.5	**0.21**	Good
Head of Casey Cr.	1458	2.7	24.7	**0.11**	Poor
Torian	3117	0.35	4.8	**0.07**	Poor
Murphy	2520	2.4	1.7	**1.41**	Poor
Johnston	1460	*2.3 Cal*	*11.5*	*0.20 Ref*	Poor
Adams	1905	*1.1 Cal*	*5.4*	*0.20 Ref*	Poor
Frederick	1867	*0.42 Cal*	*2.1*	*0.20 Ref*	Poor
Interstate	1858	*2.3 Cal*	*11.4*	*0.20 Ref*	Poor

Table 2E: English Version: Unit Base Flow (UBF) data for NE and SW Portions of the Western Mississippian Plateau.

UBF (shown in bold) is derived by dividing a spring's base-flow discharge by its basin area. Spring volumes that are difficult to gage may be calculated (*Cal*) by multiplying the apparent basin area by the reference (*Ref*) value (basins with calculated discharges, shown in italics, were not used in regression analyses). Three spring volumes were estimated (*Est*). The low UBF of two large overflow (OF) springs results from the diversion of most of the basin's base flow to an unknown location. The metric conversion factor is: **10.931** x ___ $ft^3/s/mi^2$ = ___ $L/s/km^2$. The English conversion factor is: **0.0915** x ___ $L/s/km^2$ = ___ $ft^3/s/mi^2$. *(Some basin areas and UBF have been modified by subsequent research)*

Other anomalous data from the NE study area are indicated by the excessively low UBF of the two overflow springs, Head of Wolf Creek and Head of Spring Creek. Because sizeable basins are demonstrated by the tracer tests, a significant volume of perennial underflow is indicated, which is yet to be discovered. The fluctuating ponding of tributaries by the channelized Ohio River has prevented a thorough search for these two underflow springs. Using a reference value of 0.87 L/s/km^2 (0.08 ft^3/s/mi^2), 57 L/s (2.0 ft^3/s) of additional discharge is estimated by UBF calculation for the Head of Spring Creek underflow, while the unobserved underflow of Head of Wolf Creek is estimated at about 23 L/s (0.8 ft^3/s).

Figure 17 shows the distribution of spring basins in the SW study area.

Most of the sampled springs were near the reference UBF value of 2.19 L/s/km^2 (0.20 ft^3/s/mi^2). Anomalies include Mill Stream Spring, which as stated above, is reduced by contribution from a large portion of the watershed containing thinner epikarst development and less soluble rocks. Brelsford Spring, at 2.73 L/s/km^2 (0.25 ft^3/s/mi^2), has a slightly higher than normal UBF. Although the basin area and part of the discharge from its distributary is estimated, a greater thickness of soil in the Brelsford Spring basin may account for the higher UBF. This appreciable soil thickness also reduced the development of sinkholes which hampered the search for dye injection points. Brelsford Spring ranked relatively low in the level of nitrate-N contamination (1.15-2.64 mg/L), which may relate to thicker soils as well as less intensive nutrient application. Nearby Garnett Spring, where the basin is similarly estimated from topographic divides and thicker soils are expected, also has a slightly high UBF at 2.84 L/s/km^2 (0.26 ft^3/s/mi^2).

An initial low UBF at King Spring of 1.20 L/s/km^2 (0.11 ft^3/s/mi^2), based on gaging of only the major spring, was revised upward to 2.08 L/s/km^2 (0.19 ft^3/s/mi^2) by discovery and gaging of additional springs within the basin distributary. The two additional perennial springs were mapped during a systematic spring survey by canoe and were linked to the major spring by a tracer test.

An initial high UBF at Cooksey Spring of 2.84 L/s/km^2 (0.26 ft^3/s/mi^2) was explained when the apparent basin area was enlarged after a connecting dye trace from a losing reach of West Fork. This trace revealed that Cooksey Spring was augmented by stream flow through a meander cutoff. Subtraction of an estimated cutoff contribution of 20 L/s (0.75 ft^3/s) from the Cooksey Spring discharge yielded a more appropriate UBF of 2.19 L/s/km^2 (0.20 ft^3/s/mi^2).

Other low UBF anomalies in the region include three spring basins that are tributary to Little River from the south. These are Buchanan Spring at 1.09 L/s/km^2 (0.10 ft^3/s/mi^2), Spring Hill/Herndon distributary at 1.20 L/s/km^2 (0.11 ft^3/s/mi^2) and Head of Casey Creek Spring at 1.20 L/s/km^2 (0.11 ft^3/s/mi^2). The first two basins are hypothesized to contribute an unobserved underwater discharge to Little River. Head of Casey Creek Spring may lose significant underflow through large deposits of coarse chert alluvium that cover the valley floor below the spring.

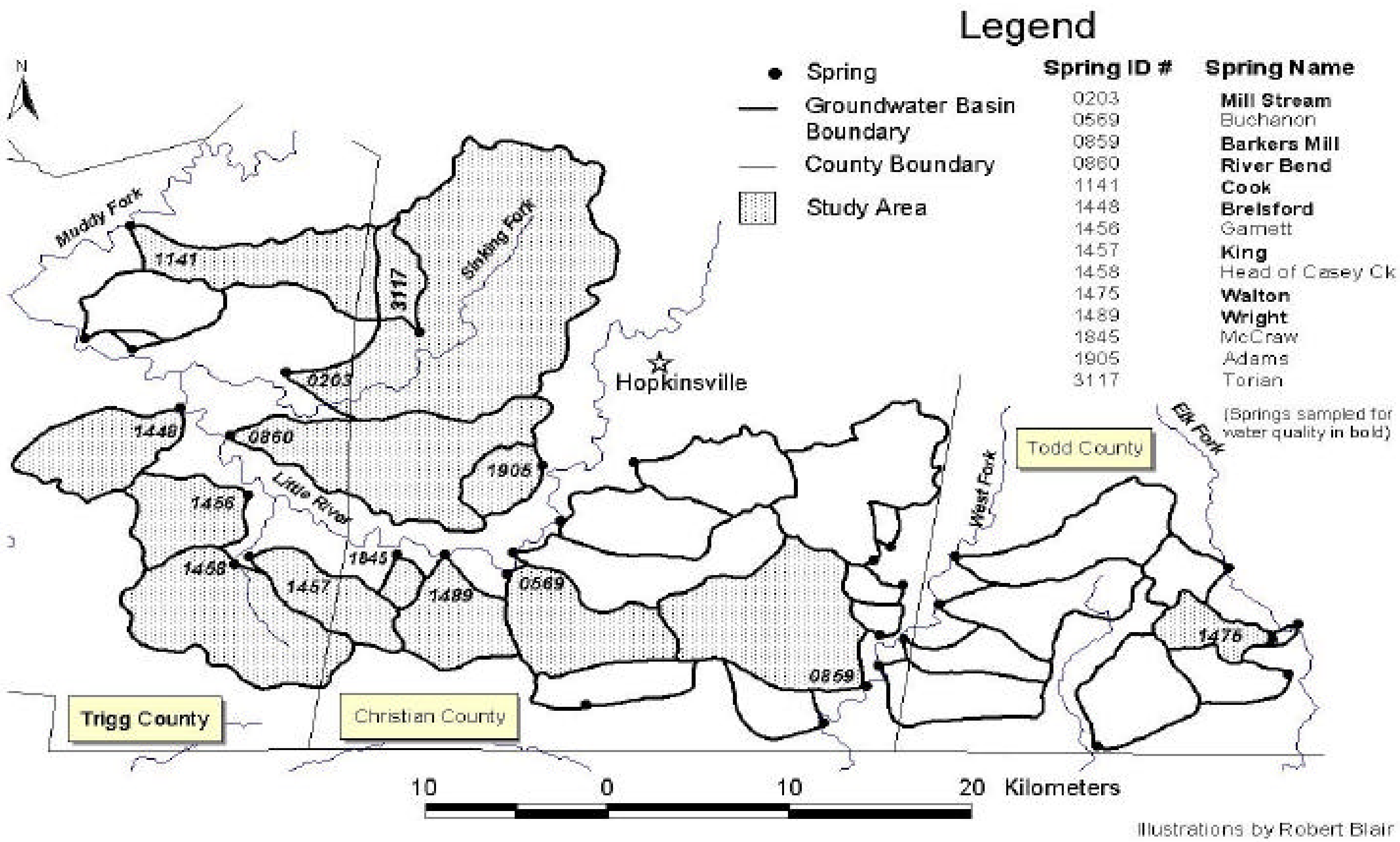

Figure 17: Karst Drainage Basins within the Southwest Study Area

The largest UBF discrepancy, however, is an excessively high anomaly at Murphy Spring, just upstream of Barkers Mill Spring. Murphy Spring, at 15.4 L/s/km^2 (1.41 ft^3/s/mi^2), is over six times the regional reference value for groundwater runoff. This high anomaly may be related to cutoff augmentation from West Fork. Previous literature suggests that Murphy Spring is the discharge point of a cutoff route from West Fork, originating at Buzzards Folly Cave, a bluff maze cave (Mason, 1982, McDowell, 1983). Mylroie and Mylroie (1990) also illustrate the Buzzards Folly cutoff route, expanding on McDowell's diagram. Cutoff augmentation from a surface stream can greatly exaggerate the UBF of a spring if the additional watershed of the cutoff contribution is not included in the calculation. A search for the cutoff origin near the maze cave has located several modest high-level overflow swallets that are activated only when West Fork rises to bank-full conditions. Therefore, at some zone beneath water level, West Fork could be losing a portion of base flow that is not obvious.

Scatter Plots of UBF Data

Discharge and *Basin Area* data were compared in a separate regression analysis for each of the two study areas. The R^2 value, "goodness of fit," represents the percentage of variation in base-flow discharge that can be explained by the basin area. Figure 18 relates discharge to basin area for ten springs in the NE study area, where the R^2 is 0.82 (1.00 is a perfect fit of data to the regression line). This indicates that a fairly strong direct relationship exists between base-flow discharge and basin area.

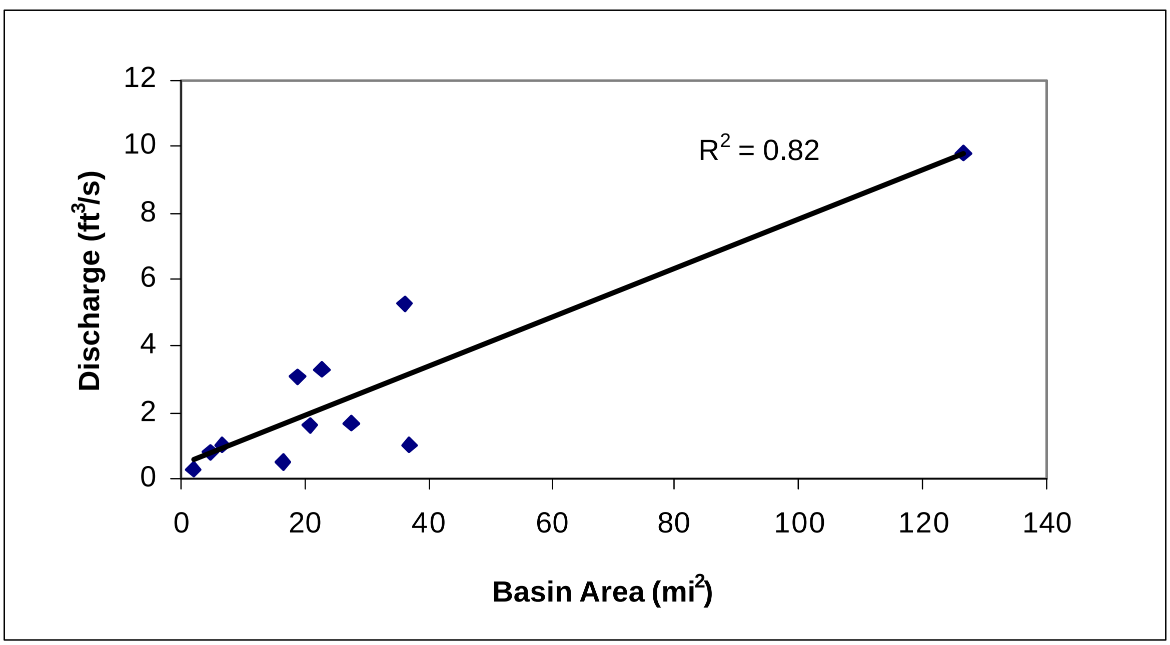

Figure 18: Scatter Plot; Discharge vs. Basin Area; NE Study Area (All Springs)

Two hydrogeologic settings exist within the NE study area: *Sinkhole Plain* (SP) karst and dissected *Sandstone Caprock* (SC) overlying soluble rock. The latter setting also includes two basins discharging from seasonal overflow springs, comprising a third sub-group. Figure 19 illustrates that discharge of seven SP basins are directly related to basin area with a strong goodness of fit (R^2) at 0.89. The two SC basins lie below the SP basins because of significantly less discharge per unit area. The two basins draining to overflow springs yield anomalously low base-flow runoff because of ungaged drainage.

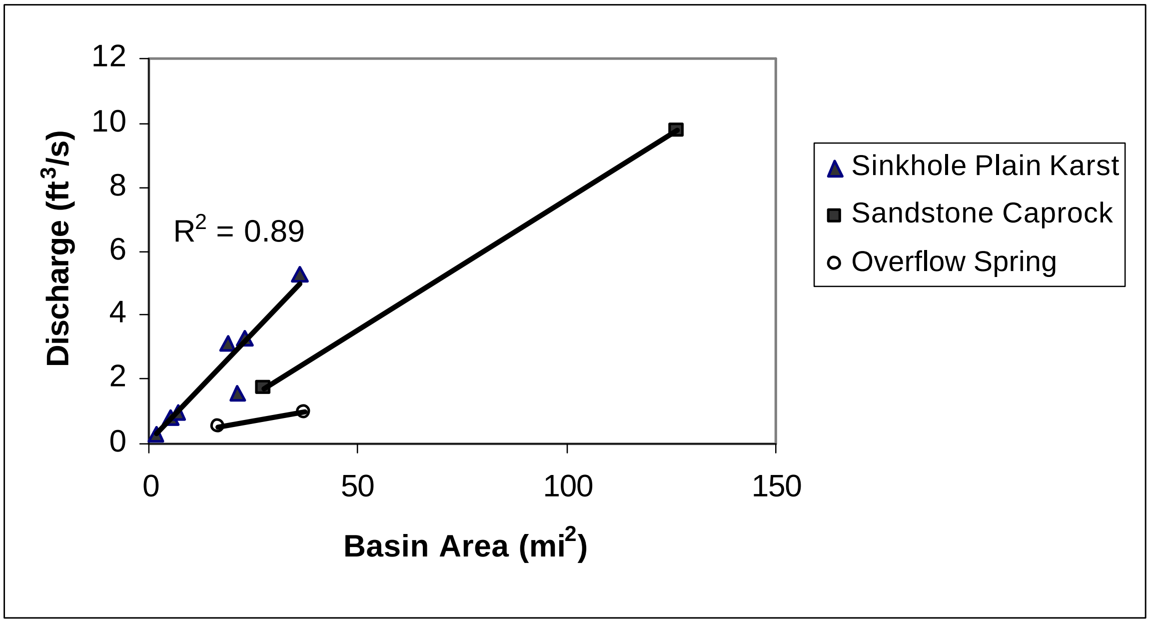

Figure 19: Scatter Plot; Discharge vs Basin Area (Northeast Study Area)

Figure 20 shows discharge/basin area intercepts for 25 springs in the SW study area. However, the goodness of fit is poor at an R^2 of 0.24. Nevertheless, a distinct trend can be seen within the data points, lying between Mill Stream and Murphy Spring. After excluding the low-discharge anomaly, Mill Stream Spring, from the graph (Figure. 21), the trend-line more closely approximates the cluster with a much higher R^2 of 0.63. Murphy Spring, a high-discharge anomaly, remains far above the trend line. Murphy Spring is excluded in Figure 22, increasing the goodness of fit of the remaining springs to an R^2 of 0.71. Five additional low-discharge anomaly basins (Torian, Buchanan, Spring Hill-Herndon, Hunt and Casey Creek, ranging from 0.8-1.3 L/s/km^2 [0.07-0.12 ft^3/s/mi^2]) are located well below the trend line. When these five basins are excluded in addition to Mill Stream and Murphy Spring, the remaining 18 basins (72% of the SW population) produce a very strong direct relationship with an R^2 of 0.97 (Figure 23). This assessment of SW springs indicates that within a select core of basins, 97% of the variability of spring discharge is explained by basin area.

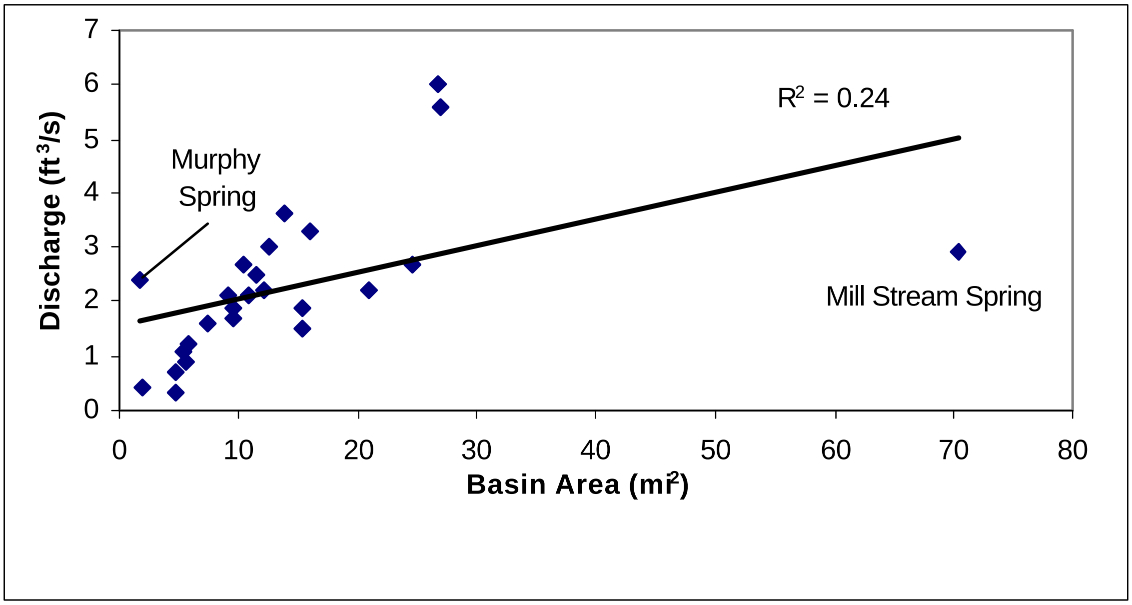

Figure 20: Scatter Plot; Discharge vs Basin Area; SW Study Area (All Springs)

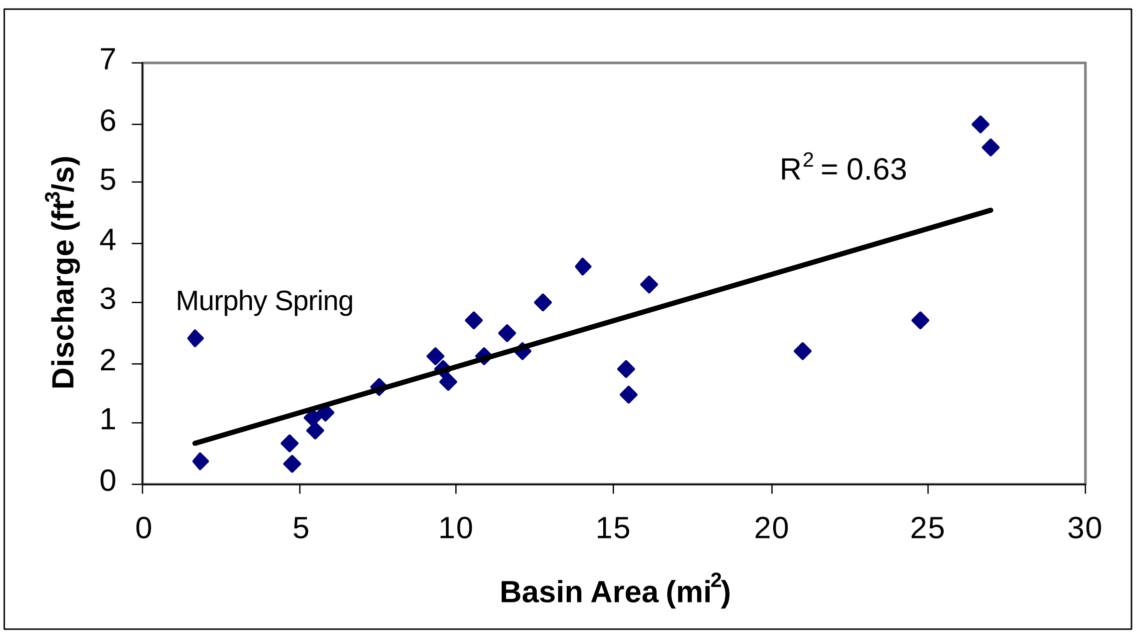

Figure 21: Scatter Plot; Discharge vs Basin Area; SW Study Area (Excluding Mill Stream Spring)

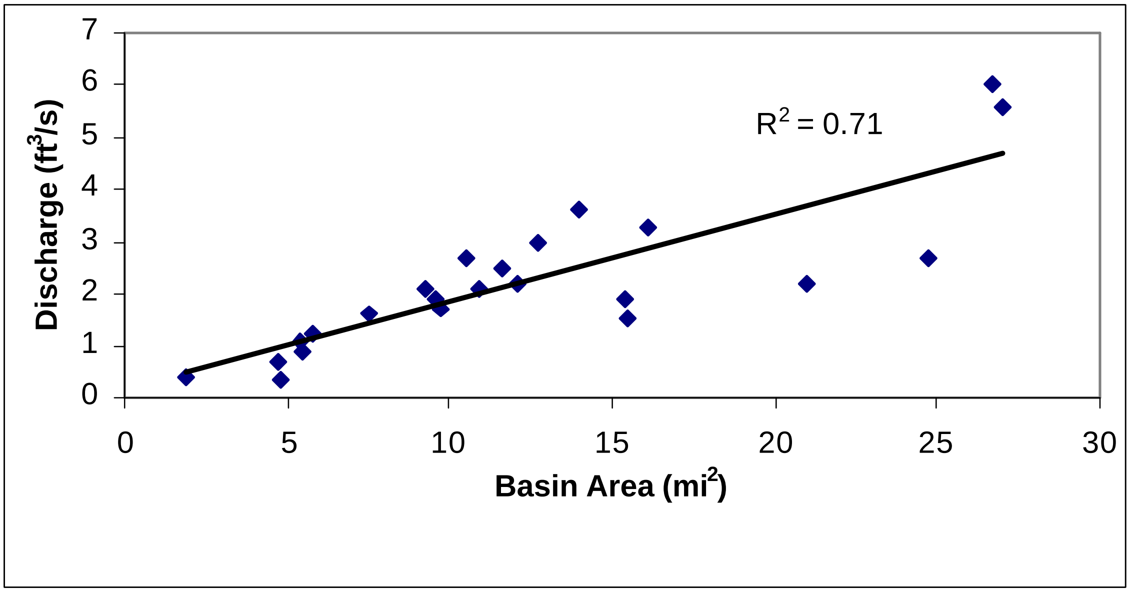

Figure 22: Scatter Plot; Discharge vs Basin Area; SW Study Area (Excluding Mill Stream and Murphy Spring)

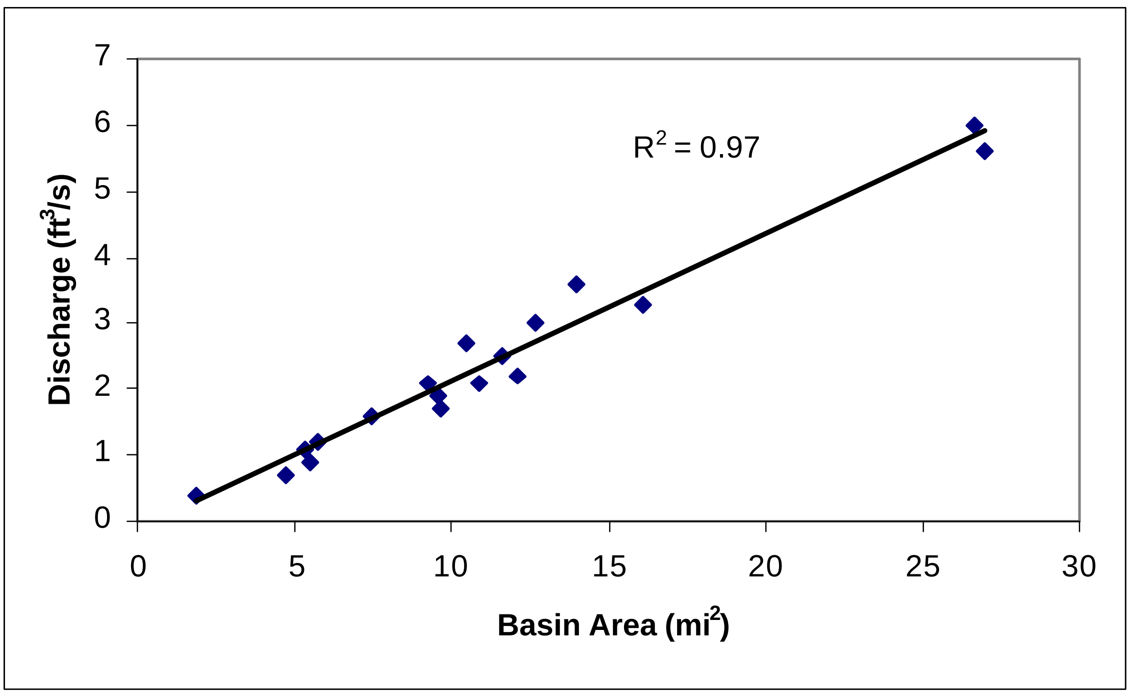

Figure 23: Scatter Plot; Discharge vs Basin Area; SW Study Area (Anomalies Excluded)

Three hydrogeologic settings exist within the SW study area and are assessed separately in Figure 24. Most basins are located within the flat-lying *Sinkhole Plain* (SP) setting in southern Christian and Todd counties. Because the population includes some anomalous UBF values, such as the high value calculated for Murphy Spring, the R^2 is lower at 0.76. Three basins are influenced by *Shallow Karst* (SK), which results in lower UBF. These basins (Torian, Hunt and Mill Stream springs) are formed within the upper Ste. Genevieve, Renault and Paint Creek limestones. In addition, the northern part of the Mill Stream Spring watershed is a non-karst sandstone terrain with relatively low UBF. The R^2 of these three SK basins is 0.74. The third group is termed *Thick Cover* (TC) karst, which is characterized by minimal sinkhole development because of abnormally thick soils to depths of 24 m (80 ft). Whereas Brelsford and Garnett springs exhibit a UBF 25% above normal, due to thick soils and greater groundwater storage, Head of Casey Creek Spring has only half of the expected UBF. This low-UBF anomaly causes the TC springs to yield a meaningless R^2 of 0.14. The low UBF of the latter spring is suspected to result from some underflow through coarse gravel that was not measured.

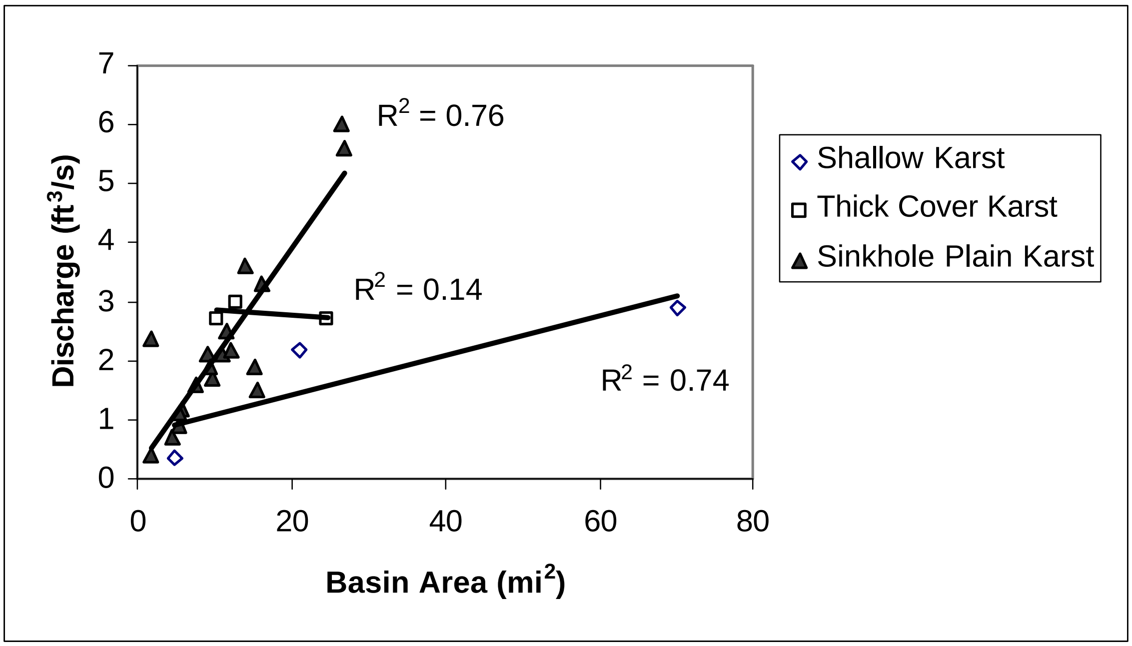

Figure 24: Scatter Plot; Discharge vs Basin Area (Southwest Study Area)